DESIGN AND IMPLEMENTATION OF SWITCHED MODE POWER SUPPLY USING PWM CONCEPTS

A Thesis Submitted in

Partial fulfillment of the requirements for the degree of

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In

Electronics and Instrumentation Engineering

By

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May 2010

National Institute of Technology Rourkela
CERTIFICATE

This is to certify that the thesis titled "*Design of SMPS Converter using PWM Feedback Mechanism*", submitted by Miss Sarika Tripathi (Roll No.- 10607021) in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Electronics and Instrumentation Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any Degree or Diploma.

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ABSTRACT

Switched Mode Power Supply (SMPS) is the most prevailing architecture for DC power supply in modern systems, primarily for its capability to handle variable loads. Apart from efficiency the size and weight of the power supplies is becoming a great area of concern for the Power Supply Designers. In this thesis an AC to DC converter SMPS circuit, having a power MOSFET for switching operation and a PWM based Feedback circuit for driving the switching of the MOSFET, is designed and simulated in NI MULTISIM circuit design environment. Further the same circuit is Hardware implemented and tested using NI ELVIS Suite.

In this design the line voltage at 220V/50Hz is taken as input, this voltage is stepped down, rectified and passed through filter capacitor to give an unregulated DC voltage. This unregulated voltage is chopped using a MOSFET switch, driven by PWM feedback signal, to control the output voltage level. An Isolation Transformer is used to isolate the DC output from input supply. The transformer output is again rectified by the high frequency Diode bridge rectifier and is filtered using a capacitor to give the regulated DC output. A Voltage regulator is connected to give the precise voltage output.

The feedback network generates a high frequency PWM signal to drive the MOSFET switch. The dc voltage at the output depends on the width of the switching pulse. The pulse width is varied with the changes in the DC output voltage level, this change in the pulse width cancels the output voltage change and the SMPS output remains constant irrespective of load variations.

CHAPTER 1

INTRODUCTION

1. INTRODUCTION

Power Electronics is the art of converting electrical energy from one form to another in an efficient, clean, compact, and robust manner for convenient utilisation. The never ending drive towards smaller and lighter product poses serious challenges for power supply designers.

The aim of the project is to design, test and implement a switched mode power supply (SMPS) circuit for AC to DC conversion, having a power MOSFET for switching operation and a PWM based feedback circuit to drive the MOSFET switch using NI MULTISIM circuit design environment and NI ELVIS Breadboard.

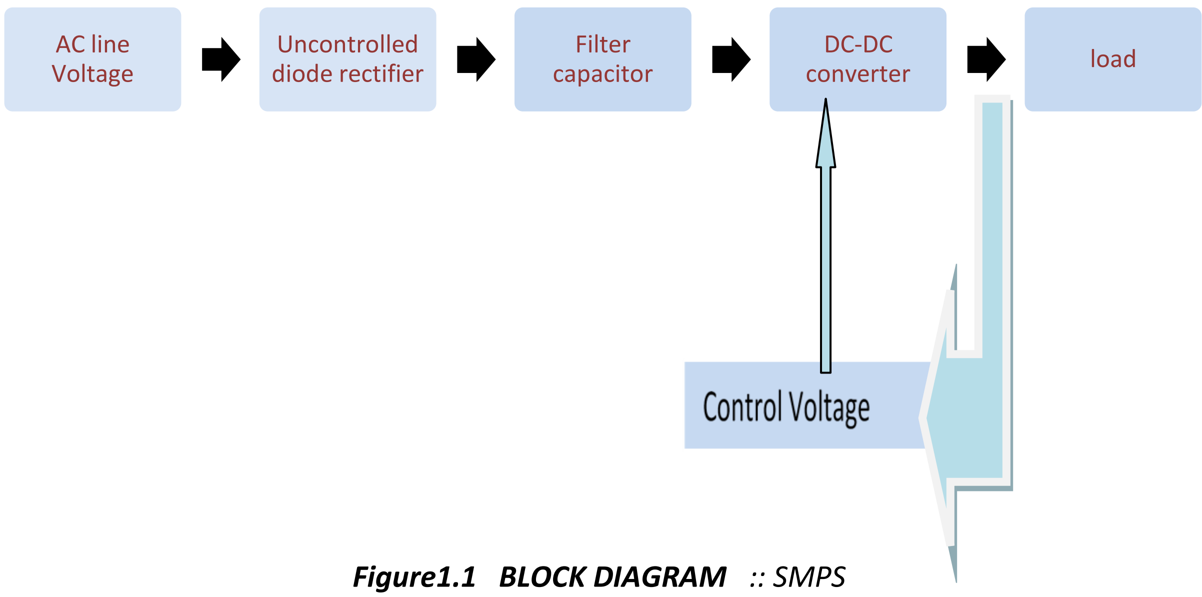

Figure1.1 BLOCK DIAGRAM *:: SMPS*

CHAPTER 2

THEORITICAL BACKGROUND

2. THERORITICAL BACKGROUND

2.1 Power Supplies:

A power supply is a component, subsystem, or system that converts electrical power from one form to another; commonly from alternating current (AC) utility power to direct current (DC) power. The proper operation of electronic devices ranging from personal computers to military equipment and industrial machinery depends on the performance and reliability of DC power supplies.

Power supplies are circuits that generate a fixed or controllable magnitude dc voltage from the available form of input voltage. Integrated-circuit (IC) chips used in the electronic circuits need standard dc voltage of fixed magnitude. Many of these circuits need well-regulated dc supply for their proper operation.

Even a commodity switch-mode power supply must be able to survive sudden peaks that far exceed its average operating levels. Engineers designing power supplies or the systems that use them need to understand their supplies behaviour under conditions ranging from quiescent to worst-case.

Today's power supplies are driving to a level of efficiency never seen before, requiring design engineers to perform numerous specialized power measurements that are time-consuming and complex.

The power supply is integral to virtually every type of line powered electronic product, and the switch-mode power supply (SMPS) has become the dominant architecture in digital computing, networking, and communications systems. A single switch-mode power supply’s performance or its failure can affect the fate of a large, costly system.

2.2 SMPS

The prevailing DC power supply architecture in most modern systems is the Switch-Mode Power Supply (SMPS), which is known for its ability to handle changing loads efficiently. The power signal path of a typical SMPS includes passive, active, and magnetic components. The SMPS minimizes the use of lossy components such as resistors and linear-mode transistors, and emphasizes components that are (ideally) lossless: switch-mode transistors, capacitors, and magnetic.

Like a linear power supply, the switched mode power supply too converts the available unregulated ac or dc input voltage to a regulated dc output voltage. However in case of SMPS with input supply drawn from the ac mains, the input voltage is first rectified and filtered using a capacitor at the rectifier output. The unregulated dc voltage across the capacitor is then fed to a high frequency dc-to-dc converter. Most of the dc-to-dc converters used in SMPS circuits have an intermediate high frequency ac conversion stage to facilitate the use of a high frequency transformer for voltage scaling and isolation. The high frequency transformer used in a SMPS circuit is much smaller in size and weight compared to the low frequency transformer of the linear power supply circuit.

The ‘Switched Mode Power Supply’ owes its name to the dc-to-dc switching converter for conversion from unregulated dc input voltage to regulated dc output voltage. The switch employed is turned ‘ON’ and ‘OFF’ (referred as switching) at a high frequency. During ‘ON’ mode the switch is in saturation mode with negligible voltage drop across the collector and emitter terminals of the switch where as in ‘OFF’ mode the switch is in cut-off mode with negligible current through the collector and emitter terminals. On the contrary the voltage-regulating switch, in a linear regulator circuit, always remains in the active region.

In this thesis firstly a simplified schematic switching arrangement is described that omits the transformer action. In fact there are several other switched mode dc-to-dc converter circuits that do not use a high frequency transformer. In such SMPS circuits the unregulated input dc voltage is fed to a high frequency voltage chopping circuit such that when the chopping circuit (often called **dc to dc chopper**) is in ON state, the unregulated voltage is applied to the output circuit that includes the load and some filtering circuit. When the chopper is in OFF state, zero magnitude of voltage is applied to the output side. The ON and OFF durations are suitably controlled such that the average dc voltage applied to the output circuit equals the desired magnitude of output voltage. The ratio of ON time to cycle time (ON + OFF time) is known as duty ratio of the chopper circuit. A high switching frequency (of the order of 100 KHz) and a fast control over the duty ratio results in application of the desired mean voltage along with ripple voltage of a very high frequency to the output side, consisting of a low pass filter circuit followed by the load. The high frequency ripple in voltage is effectively filtered using small values of filter capacitors and inductors.

SMPS technology rests on power semiconductor switching devices such as Metal Oxide Semiconductor Field Effect Transistors (MOSFET) and Insulated Gate Bipolar Transistors (IGBT). These devices offer fast switching times and are able to withstand erratic voltage spikes. Equally important, they dissipate very little power in either the On or Off states, achieving high efficiency with low heat dissipation. For the most part, the switching device determines the overall performance of an SMPS. Key measurements for switching devices include: switching loss, average power loss, safe operating area, and more.

2.3 Choice of Topology

There are several different topologies for the switched mode power supply circuits. Some popular ones are:

- Fly-back
- Forward
- Push-pull
- Half bridge
- Full-bridge

A particular topology may be more suitable than others on the basis of one or more performance criterions like cost, efficiency, overall weight and size, output power, output regulation, voltage ripple etc.

All the topologies listed above are capable of providing isolated voltages by incorporating a high frequency transformer in the circuit.

2.4 Applications of SMPS

- To reduce cost, size and weight of a power supply.
- TVs, monitors, PCs, laptop and camcorder power packs, printers, fax machines, VCRs, portable CD players, microelectronics-based devices in automotive, computing, communications, consumer electronics, and industrial applications use SMPS.

2.5 **PWM Concepts**

PWM or Pulse Width Modulation is the modulation technique where frequency and Amplitude of the pulse signal is not varied and the pulse width or the duty cycle is varied to encode the information. A common use of PWM is to control the average current or Voltage input to a device.

In this project the PWM Signal is generated as feedback control signal for driving the switching of the MOSFET switch. The output Voltage is taken as the reference level. A sine wave is generated using LMH6622MA OPAMP and 555 Timer. This sine wave signal is compared with the reference voltage using LM311 comparator, and the pulse width of the PWM is determined by this comparison. This switching period determines the voltage at the output. Thus if there is any change at the output Voltage, the corresponding change in the PWM pulse width will nullify its effect and the output voltage will be restored to desired value.

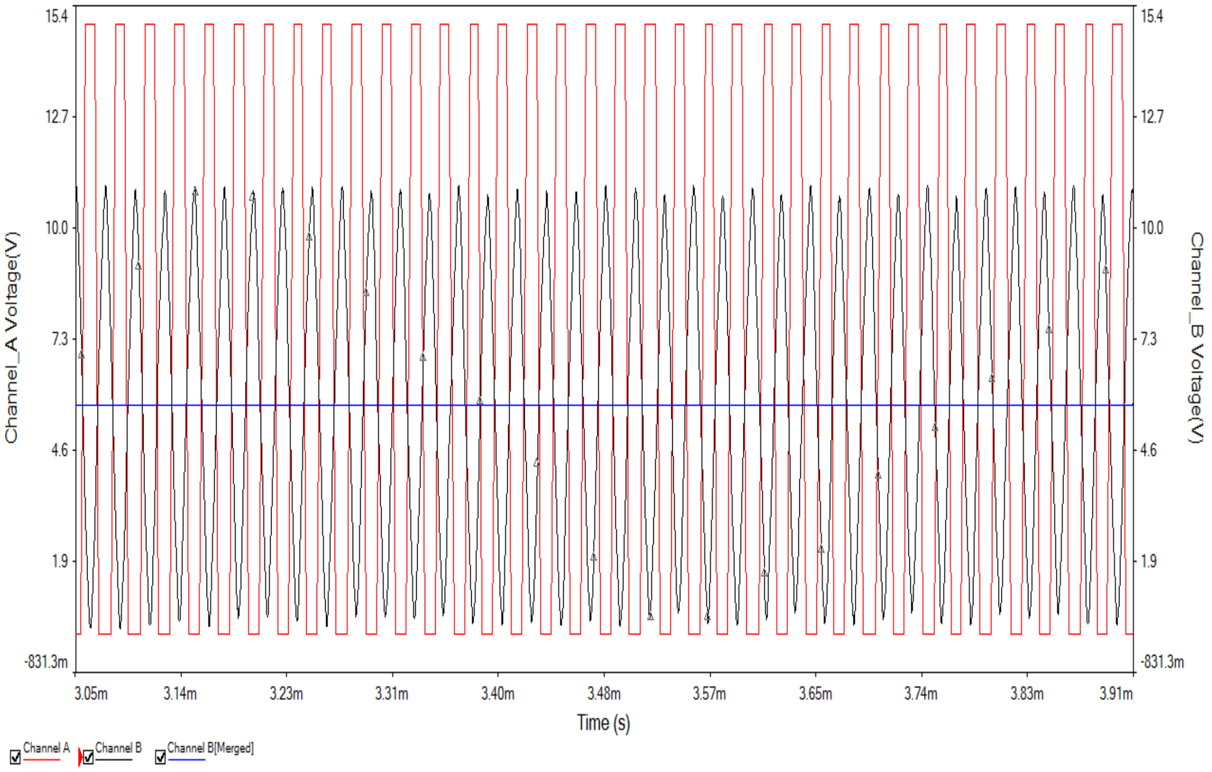

Figure2.1 PWM wave generation

CHAPTER 3

ELECRONICS DESIGN TOOLS

3. ELECTRONICS DESIGN TOOL

3.1 NI MULTISIM

NI Multisim or formerly **MultiSIM** is an electronic Schematic Capture and simulation program which is part of a suite of circuit design programs, along with NI Ultiboard. Multisim is one of the few circuit design programs to employ the original BerkeleySPICE based software simulation. MultiSIM was originally created by a company named Electronics Workbench, which is now a subsidiary of National Instruments. Multisim includes a microcontroller simulation module called MultiMCU, as well as integrated import and export features to the Printed Circuit Board layout software in the suite, Ultiboard.

Multisim is the chief competitor to Cadence OrCAD, another electronic schematic design and simulation software.

- Developer(s)

  National Instruments Electronic Workbench Group
  (formerly by Interactive Image Technologies)
- Stable release

  10.1 / 20th May 2008
- Operating system

  Microsoft Windows
- Type

  Electronic Design Automation
- License

  Proprietary EULA

3.2 **Features of MULTISIM**

You don't need to be a SPICE expert to design with Multisim. With an intuitive capture environment and an easy-to-use interface to industry-standard SPICE simulation, Multisim software can help you immediately begin designing and validating your PCBs. You can prevent costly prototype iterations and lost development time, as well as ensure quality with simulation and measurements earlier in your design flow.

The Multisim product family (Base, Full, Power Pro) provides a complete set of tools for professional PCB designers:

- Intuitive design environment
- Modeless wiring and placement
- Interactive virtual measurement instruments to view simulation and real signals
- Circuit wizards for automatically generating commonly used circuitry
- Rubber banding on parts/moves
- Fast-retrieval parts bin
- Easy export to NI Ultiboard for layout

Complex designs can be accomplished with advanced Multisim features - from 24 sophisticated SPICE analyses to a comprehensive component library - all the while taking advantage of an easy-to-use design environment. Designers can incorporate the latest parts using a custom component wizard. They can also use NI LabVIEW measurement software to introduce real measurements into simulation for rapidly prototyping and testing designs.

- More than 16,000 components, all with models ready for immediate simulation
- Device models from leading manufacturers such as Analog Devices™ and Texas Instruments™
- Easy addition of new parts and simulation models
- Comprehensive suite of analyses, including Monte Carlo and Worst Case

3.3 **NI MULTISIM 11**

Multisim and Ultiboard 11.0 introduce a number of new features and enhancements to make capturing designs, simulating behaviour, and defining board layout faster and easier. Feedback circuit of this project work was designed in NI MULTISIM 11 and rest of the circuit was imported from version 10 to 11 and then integrated in MULTISIM 11 for final simulation.

3.4 **NI ELVIS**

The National Instrument's Educational Laboratory Virtual Instrumentation Suite(NI ELVIS) is a LABVIEW based-design and prototyping environment for Universities science and engineering laboratories. The NI ELVIS featuring an integrated suite of 12 instruments in one compact form factor is ideal for hands-on learning (http://www.ni.com/nielvis/). NI ELVIS is a primary component of the NI electronics education platform along with NI Multisim, the leading tool for SPICE simulation and schematic capture, and NI LabVIEW software. (http://zone.ni.com/devzone/cda/tut/p/id/7159)

3.5 **Components of NI ELVIS**

NI ELVIS includes 12 of the most commonly used laboratory instruments including an oscilloscope (scope), digital multimeter (DMM), function generator, variable power supply, dynamic signal analyzer (DSA), bode analyzer, 2- and 3-wire current-voltage analyzer, arbitrary waveform generator, digital reader/writer, and impedance analyzer in a single platform. This compact, yet powerful assortment of instruments translates into cost savings for the lab, both in terms of lab space as well as lower-maintenance costs.(http://zone.ni.com/devzone/cda/tut/p/id/7159)

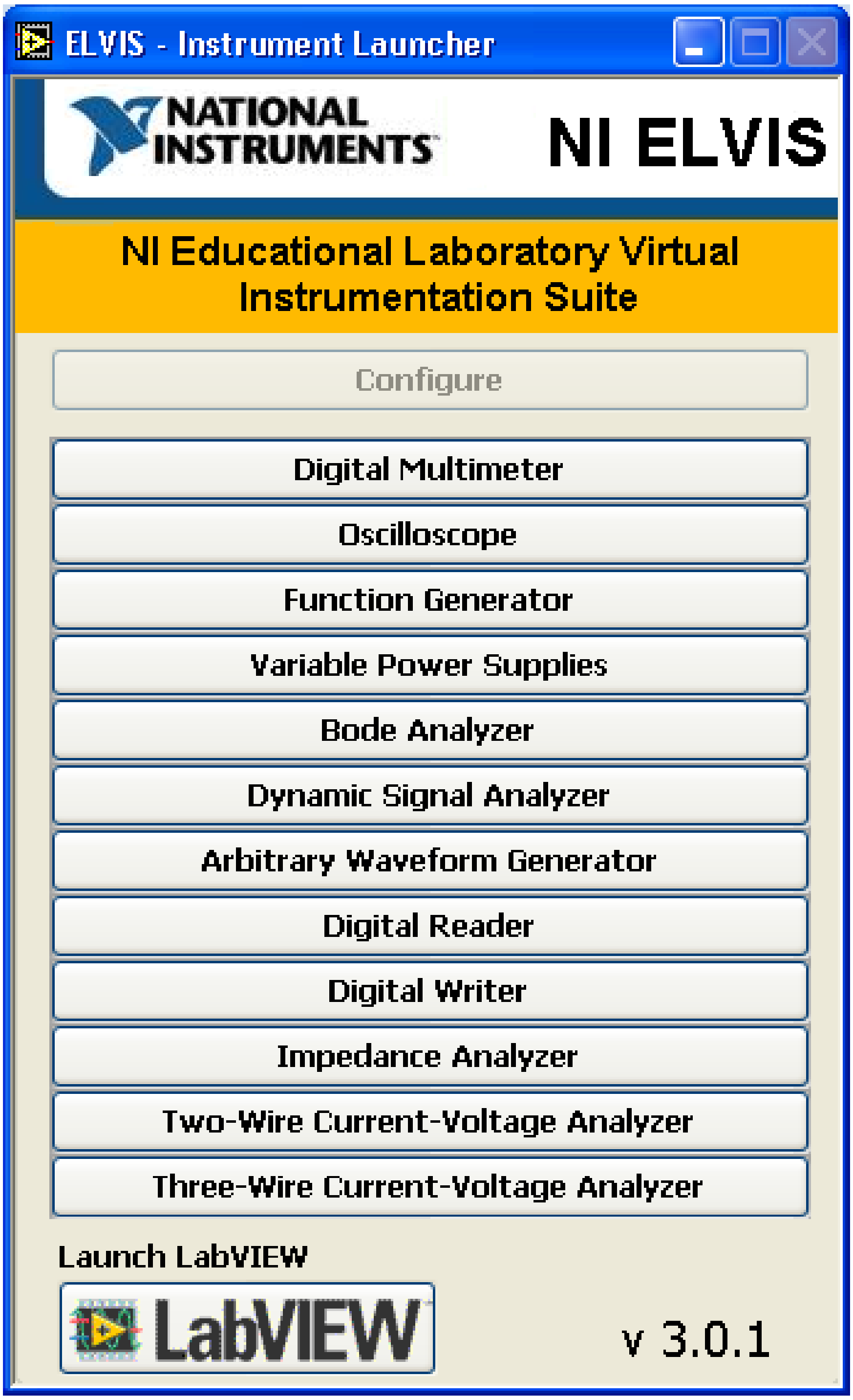
ELVIS - Instrument Launcher
NATIONAL INSTRUMENTS
NI ELVIS
NI Educational Laboratory Virtual Instrumentation Suite
Configure
Digital Multimeter
Oscilloscope
Function Generator
Variable Power Supplies
Bode Analyzer
Dynamic Signal Analyzer
Arbitrary Waveform Generator
Digital Reader
Digital Writer
Impedance Analyzer
Two-Wire Current-Voltage Analyzer
Three-Wire Current-Voltage Analyzer
Launch LabVIEW
LabVIEW
v 3.0.1

Figure 3.1

Following Components were used for this project work::

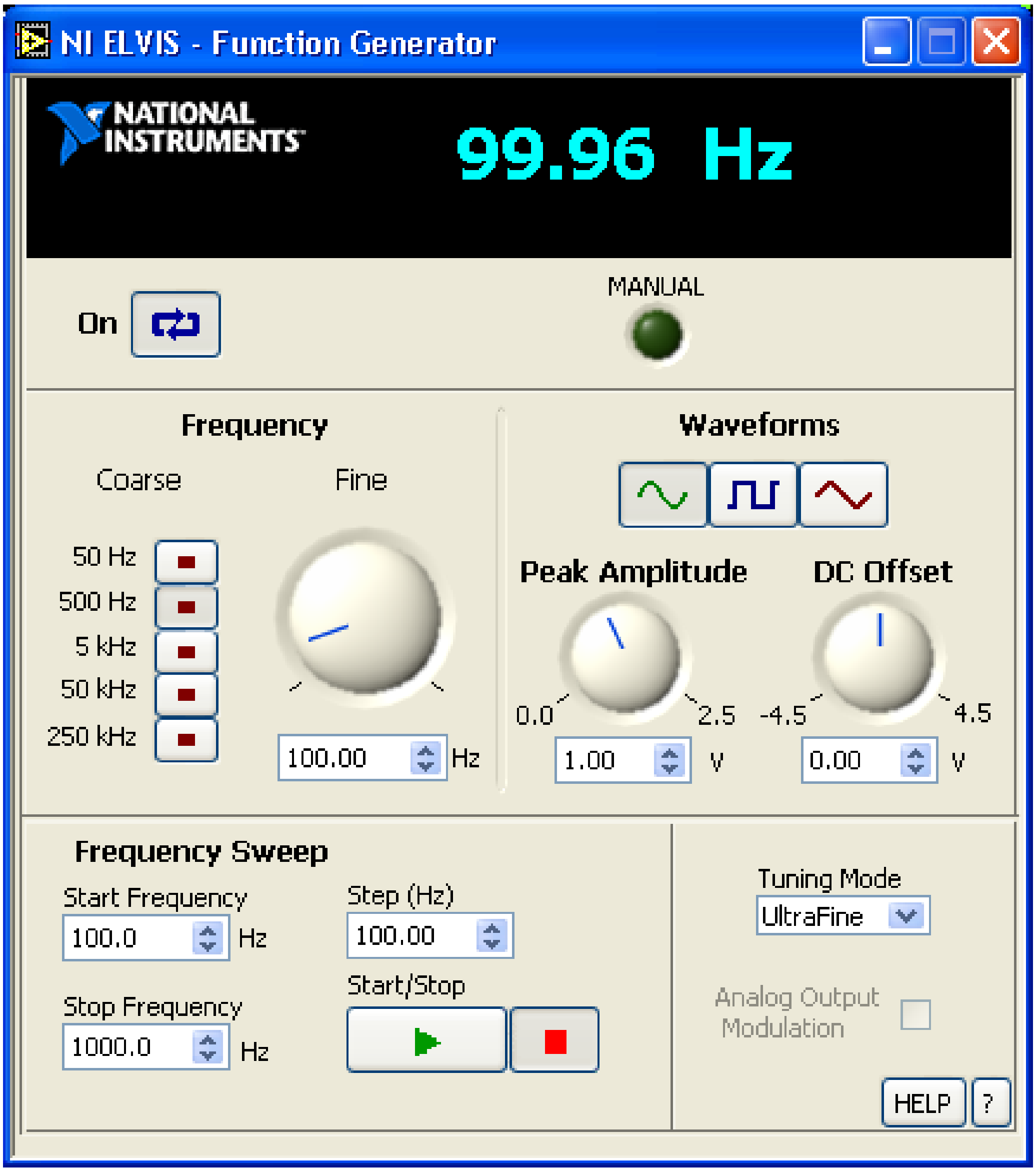

Figure 3.2 The Function Generator

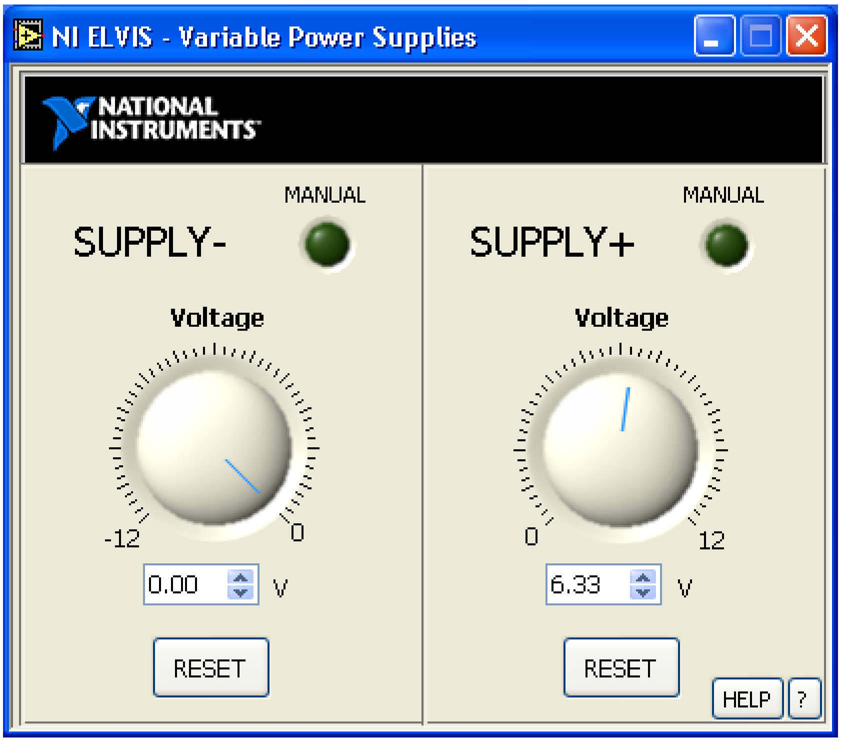

Figure 3.3 Variable Power supplies

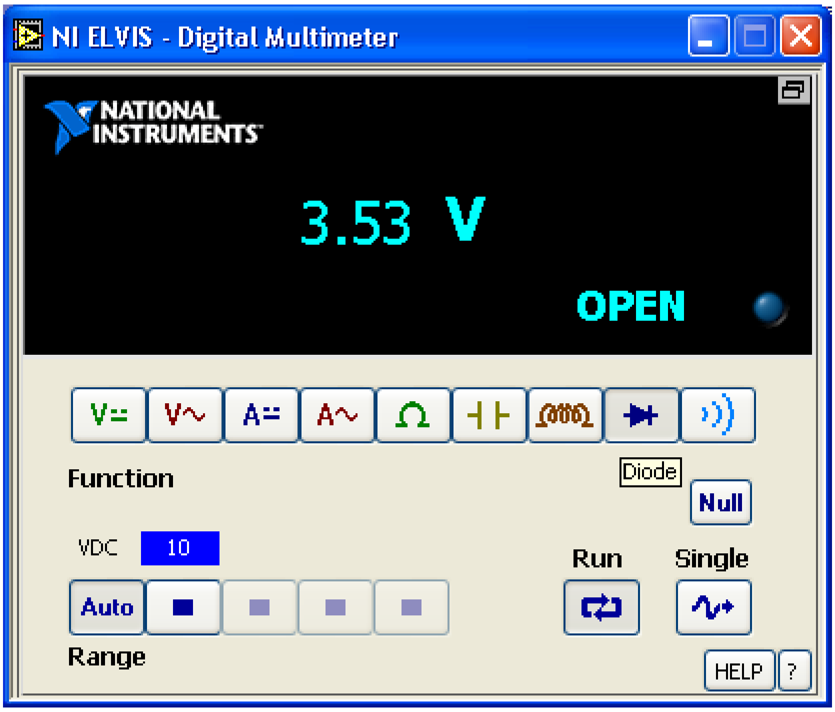

Figure 3.4 Digital Multimeter

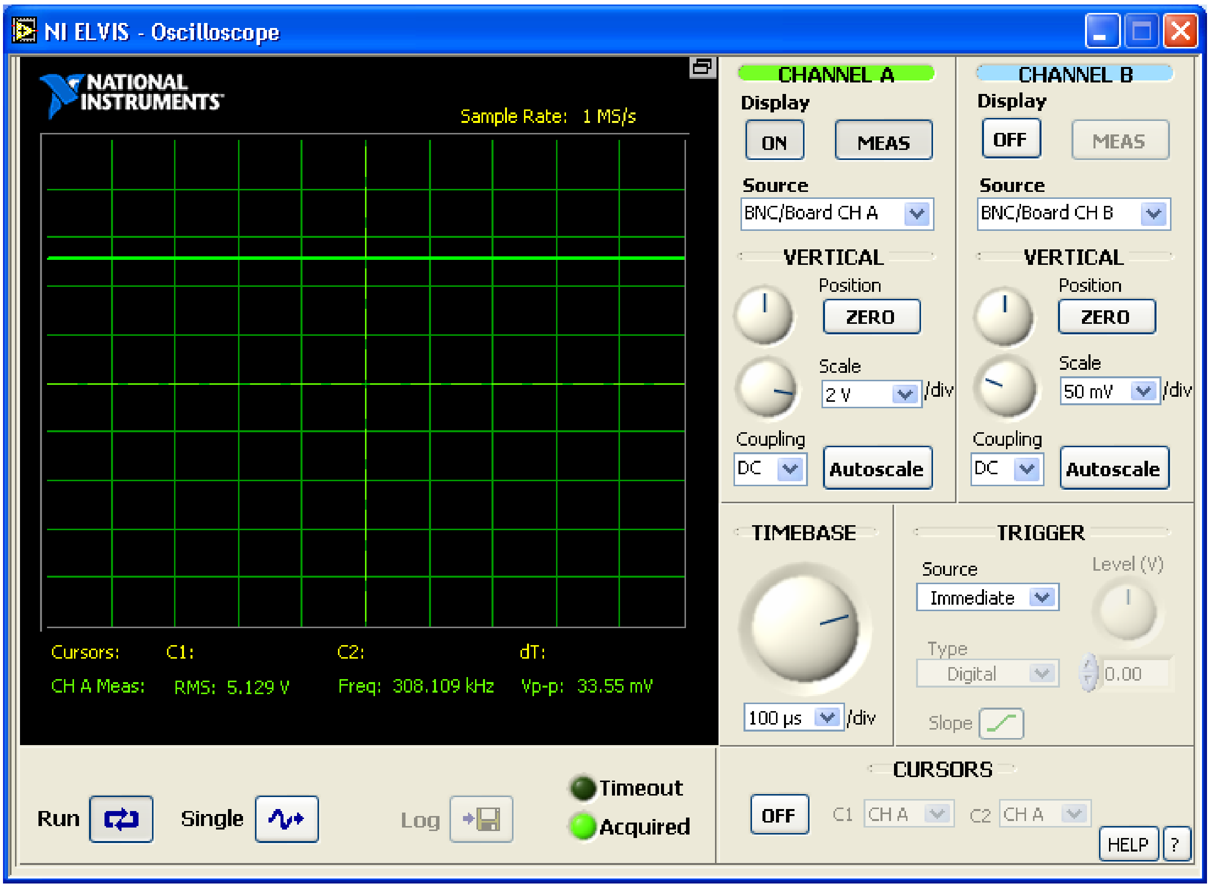

Figure 3.5 Oscilloscope

Figure 3.6 Complete Circuit Setup with NI ELVIS

CHAPTER 4

COMPONENTS SELECTION

4. COMPONENTS SELECTION

For NI MULTISIM

4.1 **Power supply**

AC power

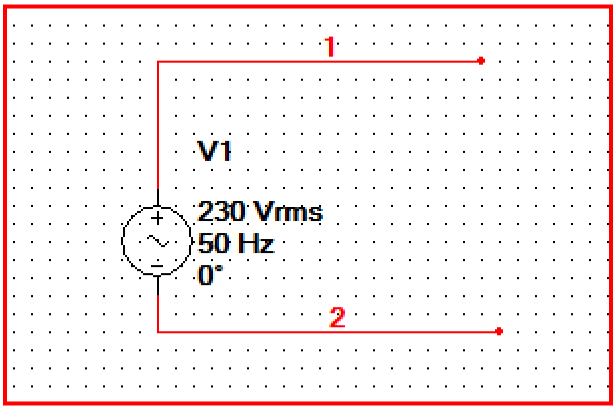

Figure 4.1

Voltage RMS = 230V

Voltage offset= 0V

Frequency (f)= 50Hz

Time Delay = 0ns

4.2 **Step-Down Transformer**

'Transformer Rated' available in multisim Library

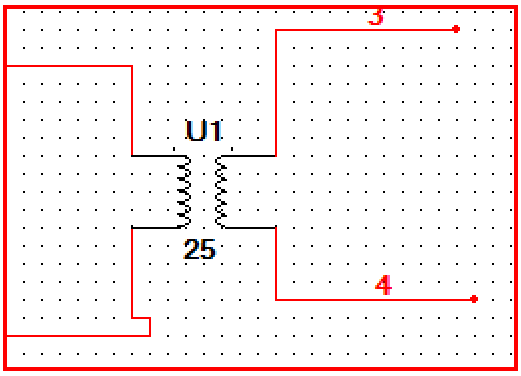

Figure 4.2

Primary Voltage (max) = 350V

Primary Current (max) = 5A

Secondary Voltage (max) = 15V

Secondary Current (max) = 1A

Output Power (max) = 5kVA

Primary to Secondary Turns Ratio = 20

Leakage Inductance = 1mH

Primary Winding Resistance =1Ohm

Secondary Winding Resistance = 1Ohm

4.3 **Unregulated Rectifier**

'1J4B42' --- Single Phase Bridge Rectifier

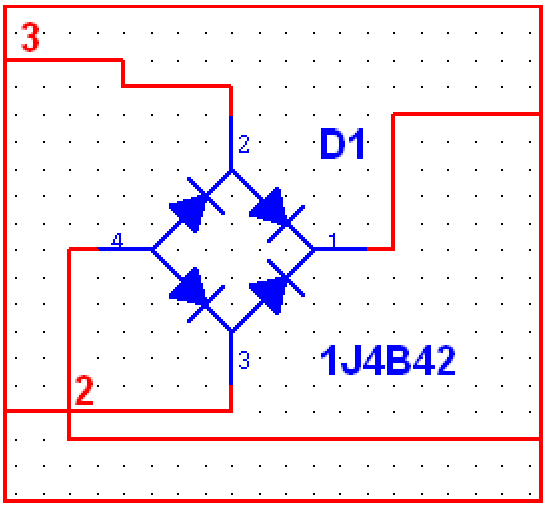

Figure 4.3

Repetitive Peak Reverse Voltage (max) = 600V

Average Output Rectified Current = 1 A

Junction Temperature = -40 to 150 ^{o}C

Peak Forward Voltage (max) = 1V

4.4 **MOSFET for Switching Application**

BS170

N-Channel Enhancement Switching Transistor

- Low On- resistance
- High Switching Speed
- Low Capacitances

Used for ::

Analog and/or Digital Switch
Switch Driver
Converters/Choppers

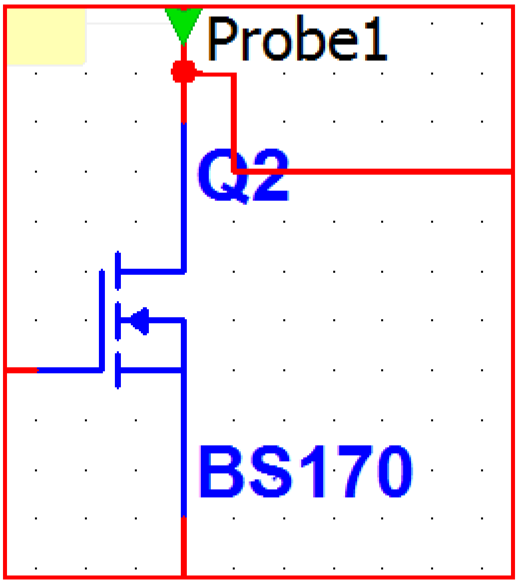

Figure 4.4

VDS max. = 20V

VGS max. = +15/-40 V

I_D max. = 50 mA

R_{DS} (typ) = 25Ω

t_{on} = 1ns

t_{off} = 5ns

4.5 **High Frequency Isolation Transformer**

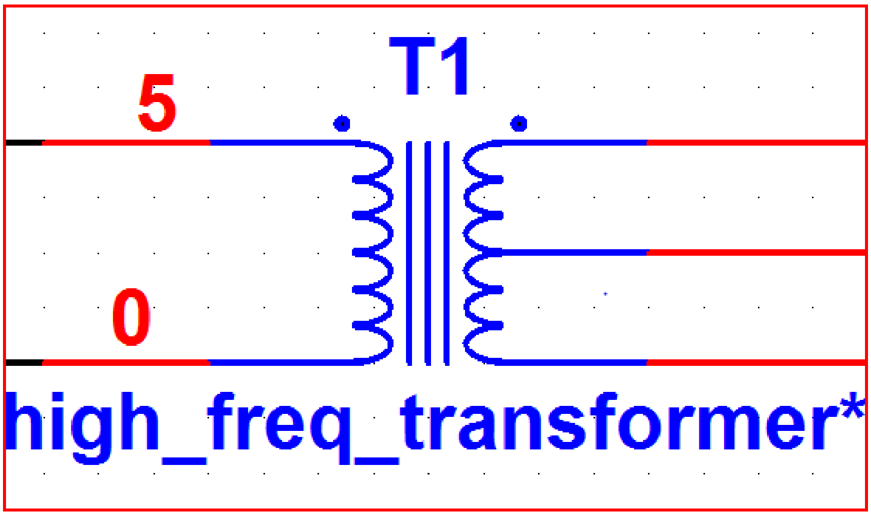

Figure 4.5

4.6 **Rectifier with high Frequency Diode**

IN4148, Fast Switching Diodes

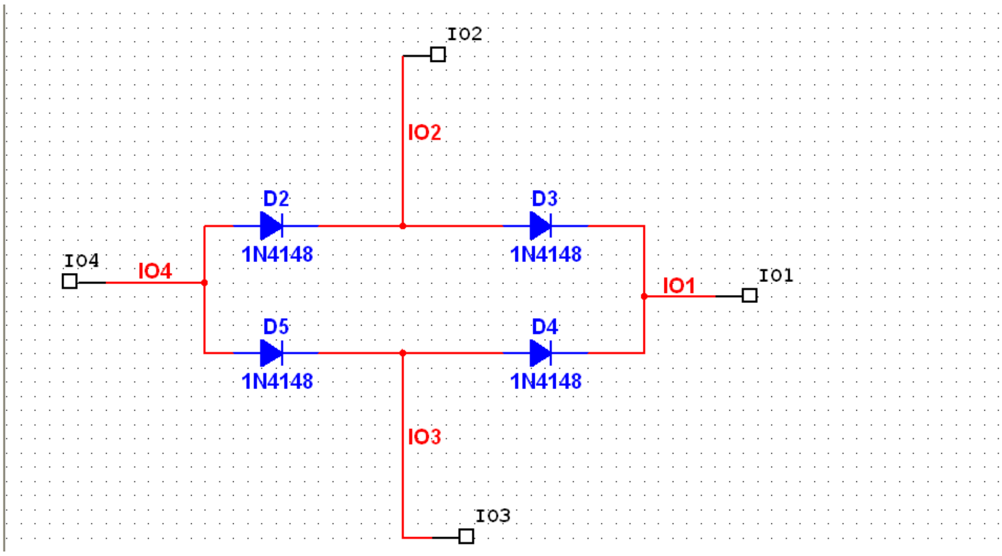

Figure 4.6

Repetitive peak reverse voltage = 100V

Reverse Voltage = 70V

Forward Voltage (max) = 1V

Average Forward current = 150 mA

Reverse Current (max) = 50 mA

Breakdown Voltage (min) = 100V

Diode Capacitance (max) = 4 pF

Rectification Efficiency (min) = 45%

Reverse Recovery Time = 8ns

4.7 **Voltage Regulator**

LM7805CT

3 terminal-1A Positive Voltage regulator

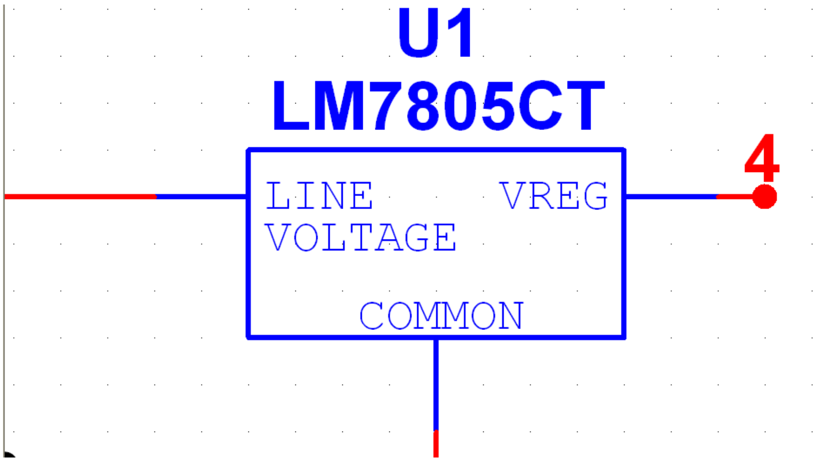

Figure 4.7

• Output Current up to 1A

• Output Voltage of 5V

• Thermal Overload Protection

• Short Circuit Protection

• Output Transistor Safe Operating Area Protection

Line regulation = 4-100mV

Load regulation = 9-100 mV

Quiescent Current = 5mA

Dropout Voltage = 2V

Peak current = 2.2 A

4.8 **555 Timer**

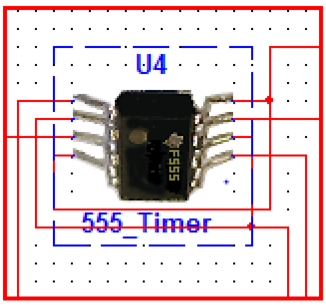

Figure 4.8

4.9 **LMH6622MA OPAMP**

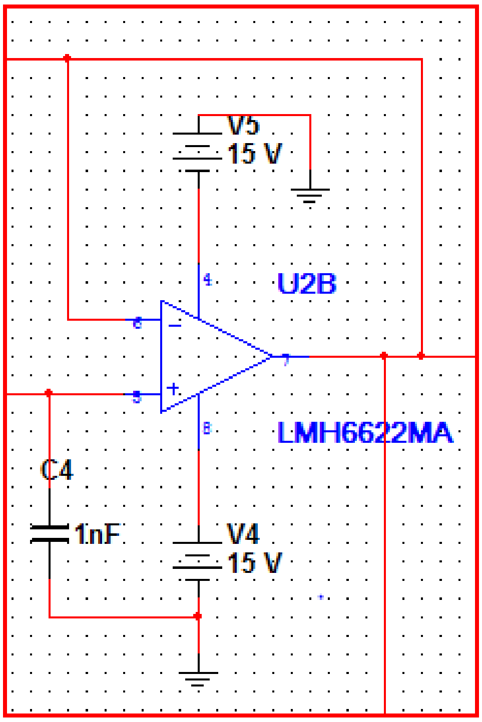

Figure 4.9

4.10 **LM311N comparator**

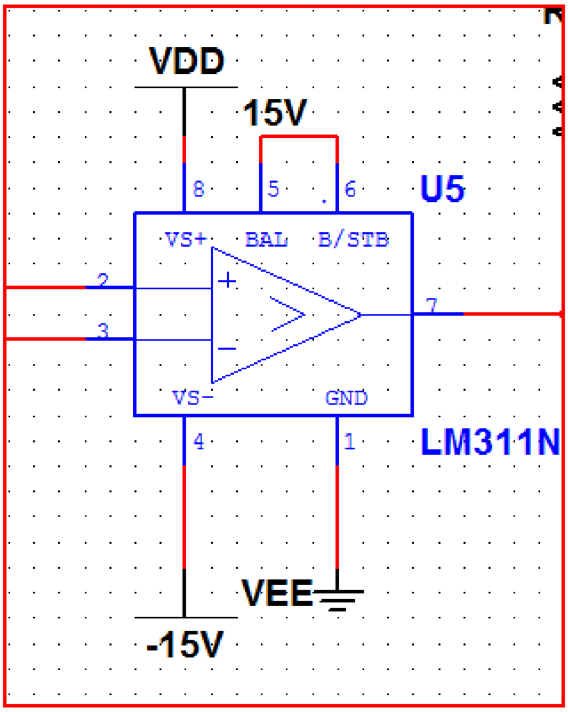

Figure 4.10

CHAPTER 5

TESTING CIRCUITS AND SIMILATION RESULTS

5. TESTING CIRCUITS AND SIMULATION RESULTS

5.1.1 **Following Circuit was designed for AC-DC conversion**

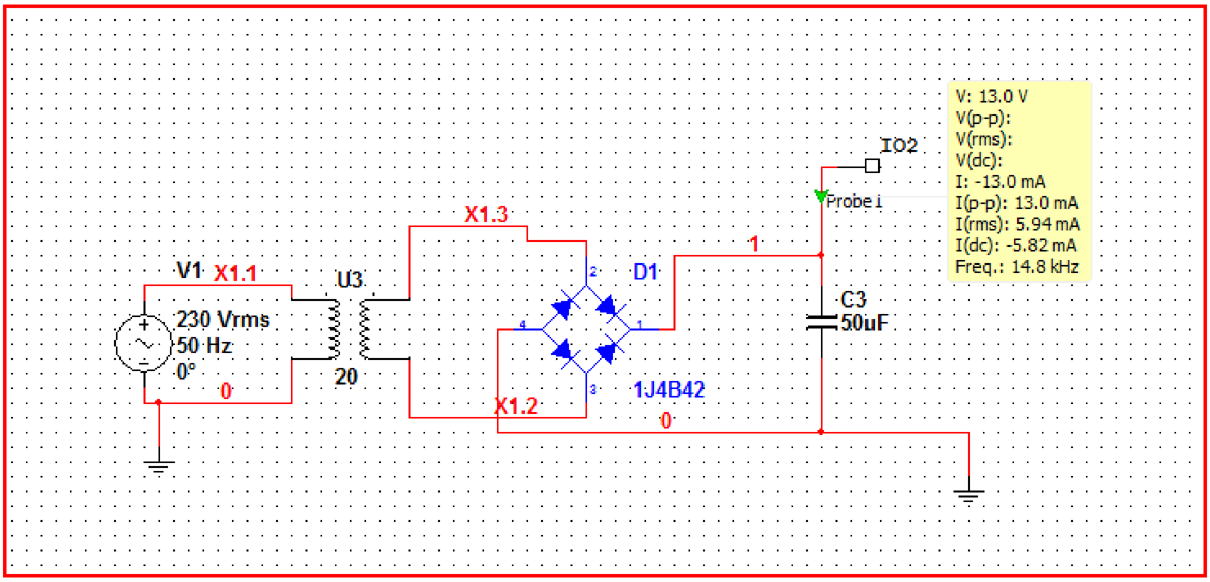

Figure 5.1

5.1.2 **Simulation Output of AC-DC conversion**

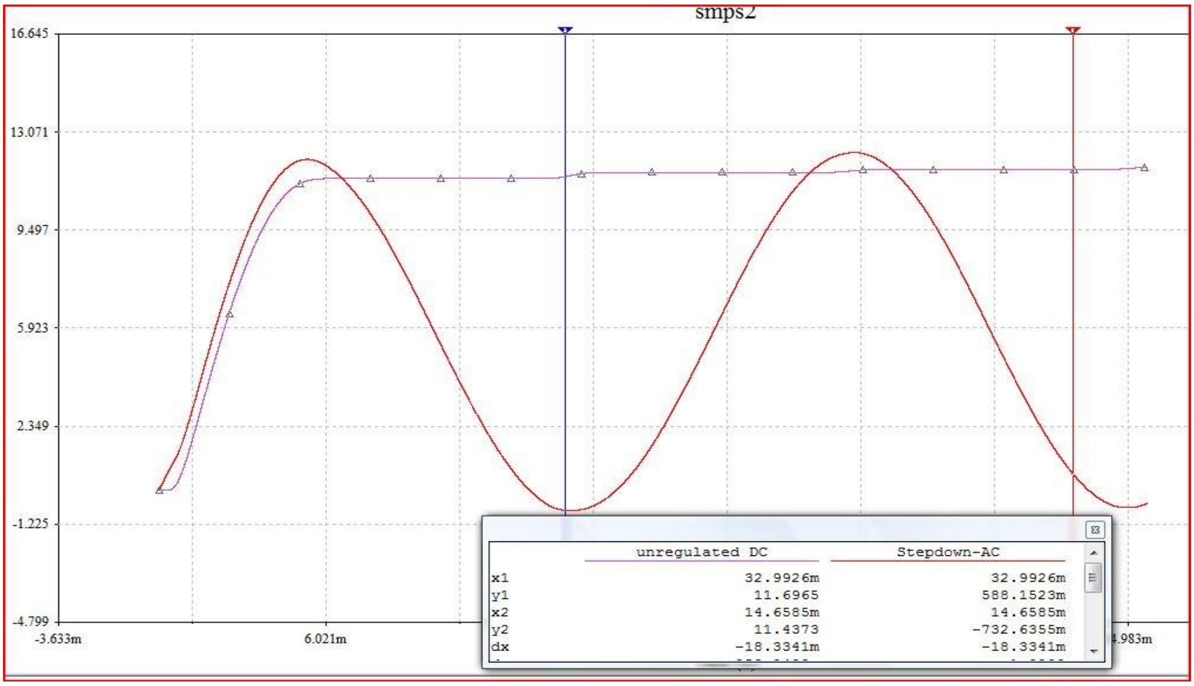

Figure 5.2

5.2.1 **Circuit for Analysis of MOSFET Switch performance**

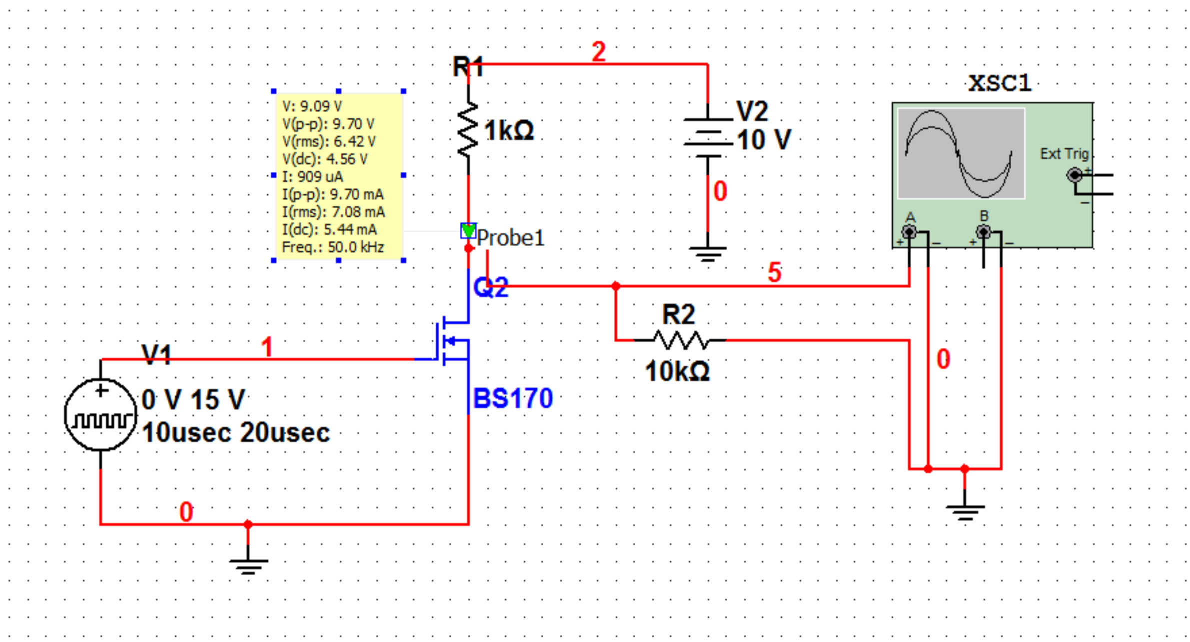

Figure 5.3

5.2.2 **Simulation output for MOSFET Switch at 50kHz**

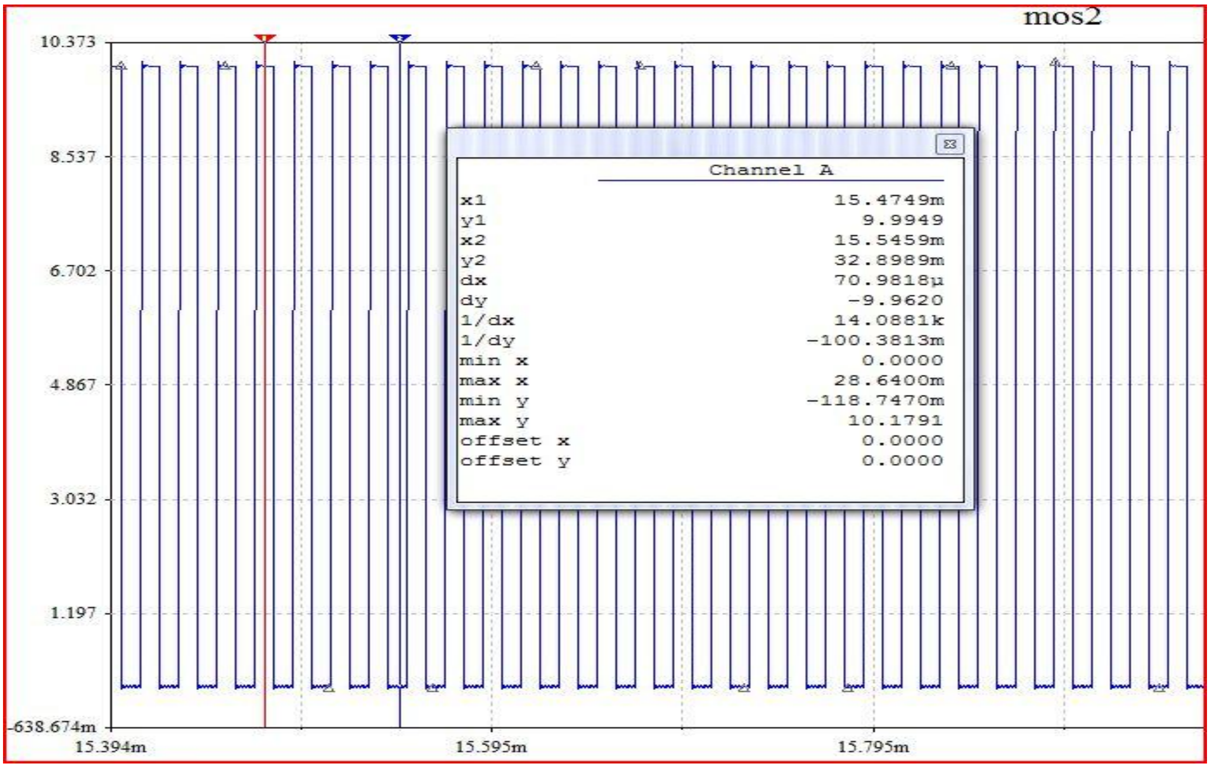

Figure 5.4

5.3.1 **Circuit of Analysis of Voltage regulator combined with Rectifier**

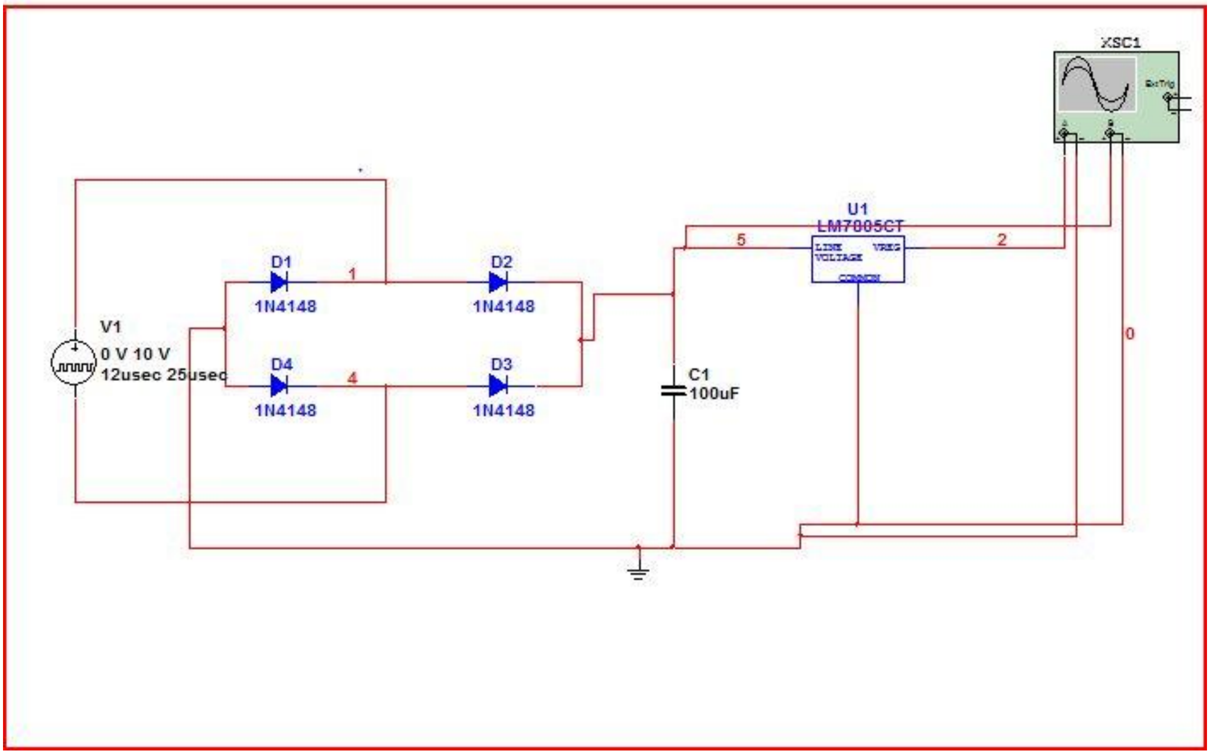

Figure 5.5

5.3.2 **Simulation Output of Voltage Regulator performance**

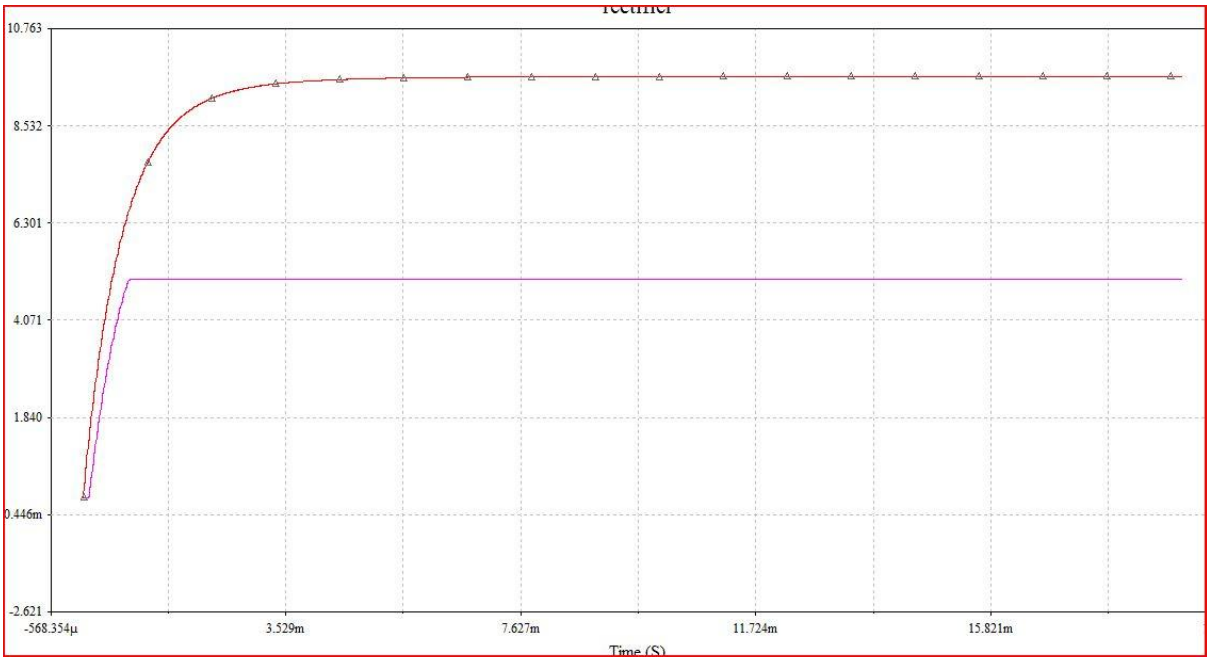

Figure 5.6

5.4.1 **Open Loop Circuit Without Isolation Transformer**

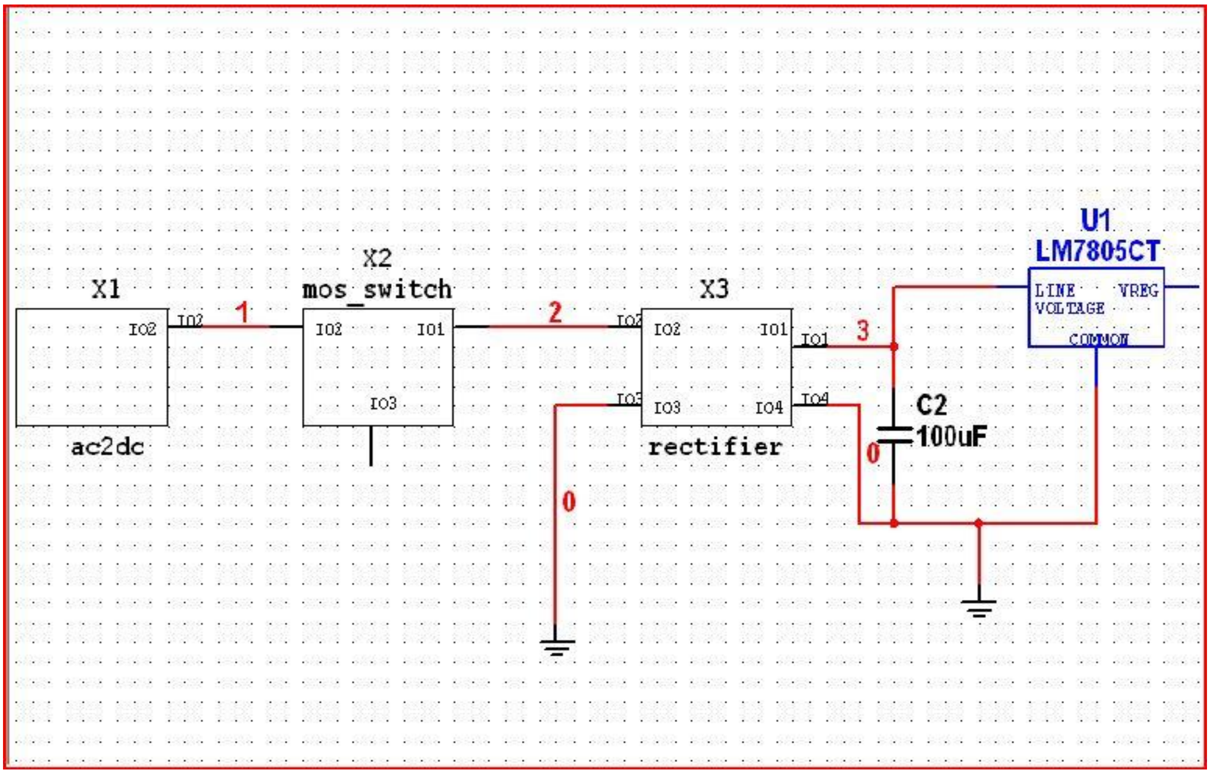

Figure 5.7

5.4.2 **Simulation Output of Open Loop Circuit**

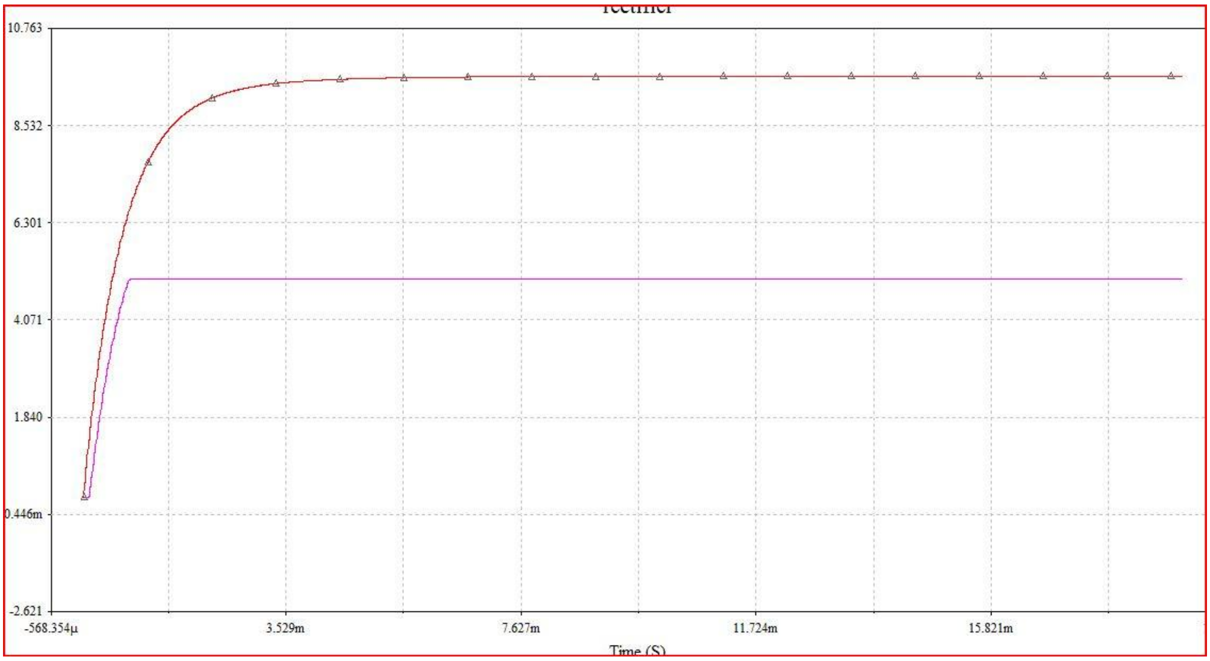

Figure 5.8

5.5.1 **Feedback Circuit**

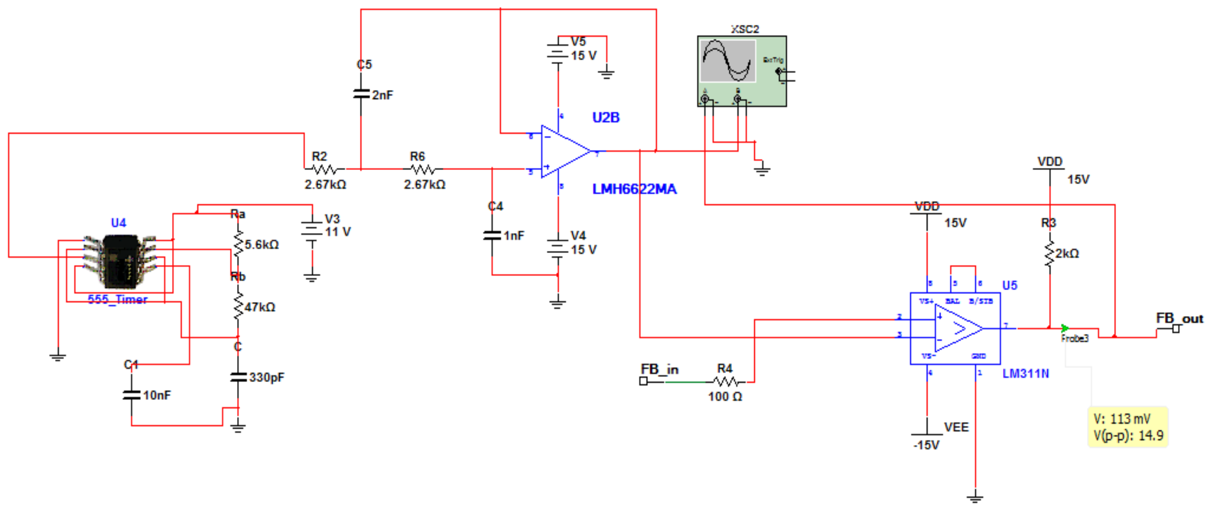

Figure 5.9

5.5.2 **Feedback Circuit Simulation Output**

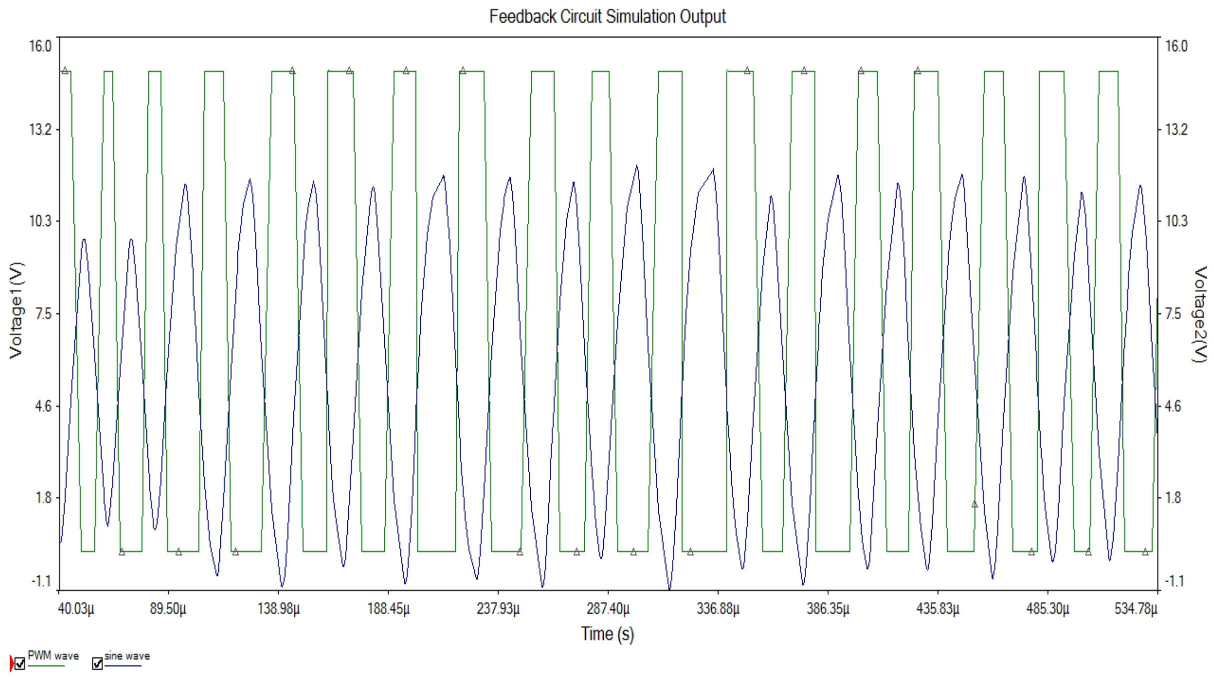

Figure 5.10

5.6.1 **SMPS Circuit**

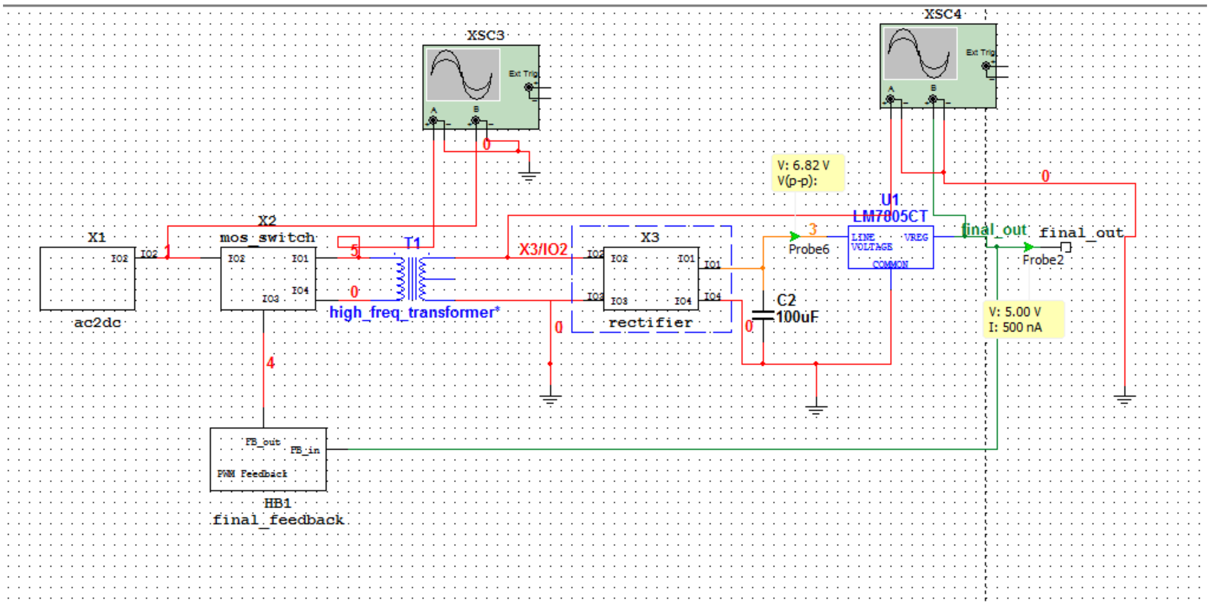

Figure 5.11

5.6.2 **SMPS Output**

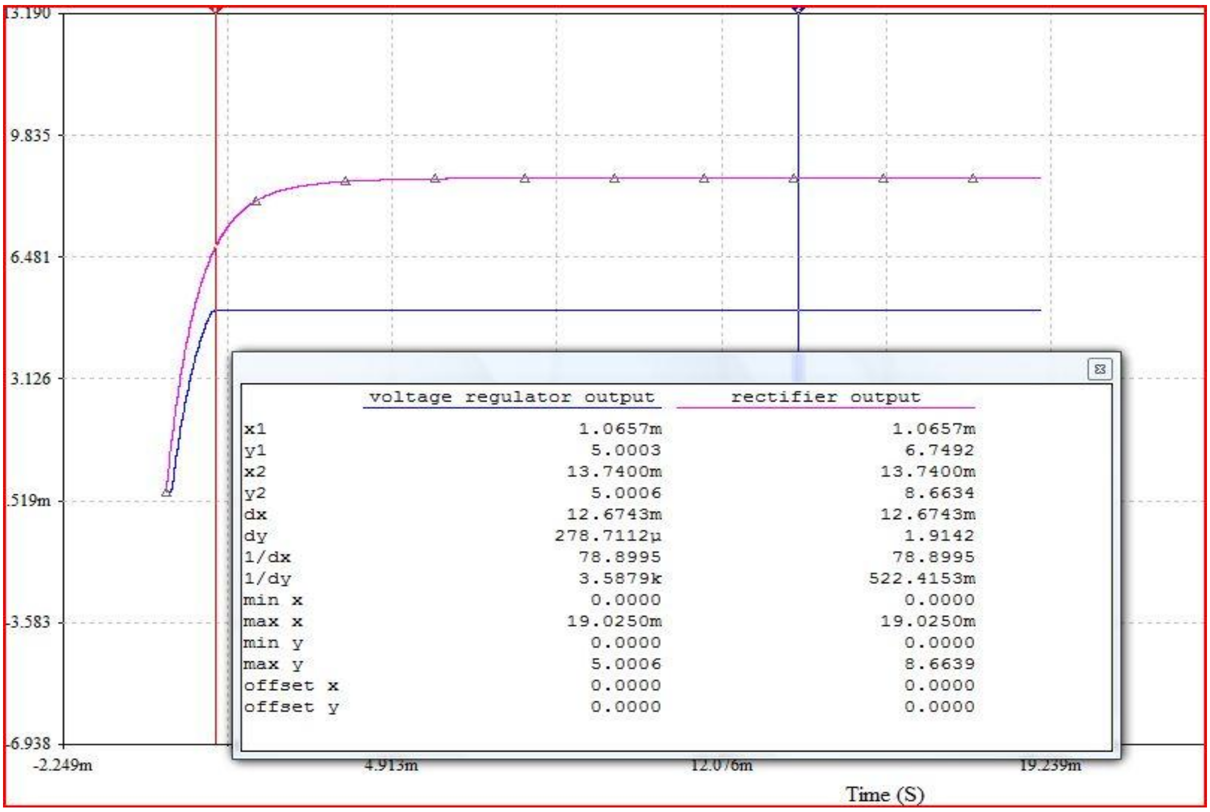

Figure 5.12

CHAPTER 6

HARDWARE IMPLIMENTATION ON NI ELVIS

6. HARDWARE IMPLEMENTATION ON NI ELVIS

The SMPS circuit designed in NI MULTSIM was further implemented in hardware using NI ELVIS as the suitable platform for circuit implementation and testing.

6.1 **Component Used**

Figure 6.1

6.1.1 **Step down Transformer**

1.6 AMP

12 0 12 configuration

6.1.2 **Diode 1N4007**

bridge Rectifier

6.1.3 **BS 170 MOSFET**

Switch

6.1.4 **Radio Transformer**

Isolation Transformer

6.1.5 **Diode 1N4148**

High frequency rectifier

6.1.6 **555 Timer**

Square wave Generation

6.1.7 **TLO6021 OPAMP**

Sine wave Generation

6.1.8 **LM311 Comparator**

PWM Switch driver signal

6.1.9 **LM 7805CT**

Voltage Regulator

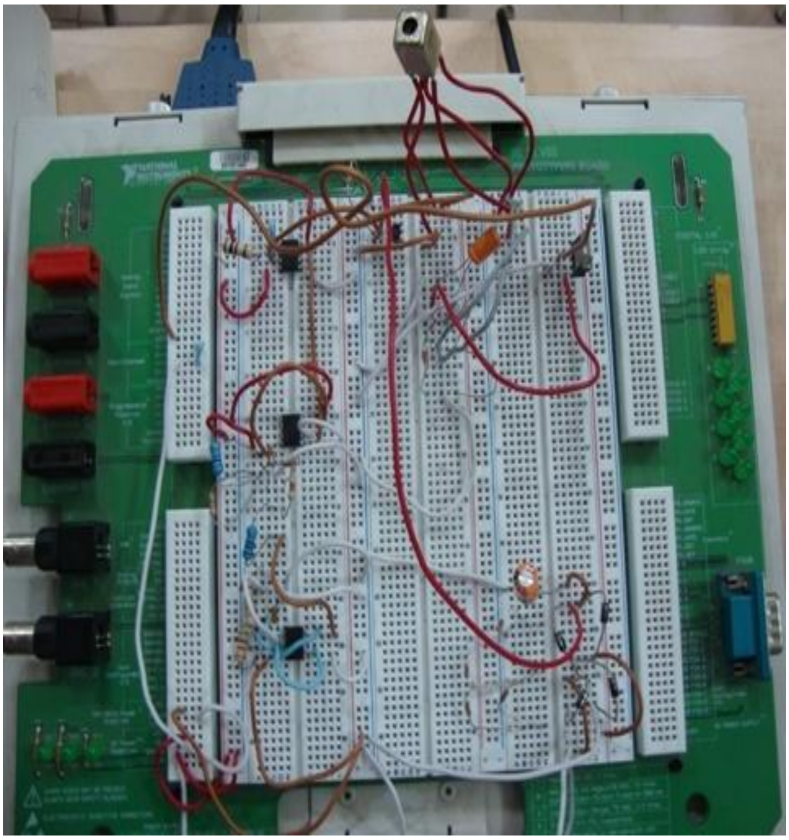

Figure 6.2 SMPS circuit on NI ELVIS

6.2 Simulation Outputs
OPEN LOOP

6.2.1 Stepped Down AC Voltage from Transformer

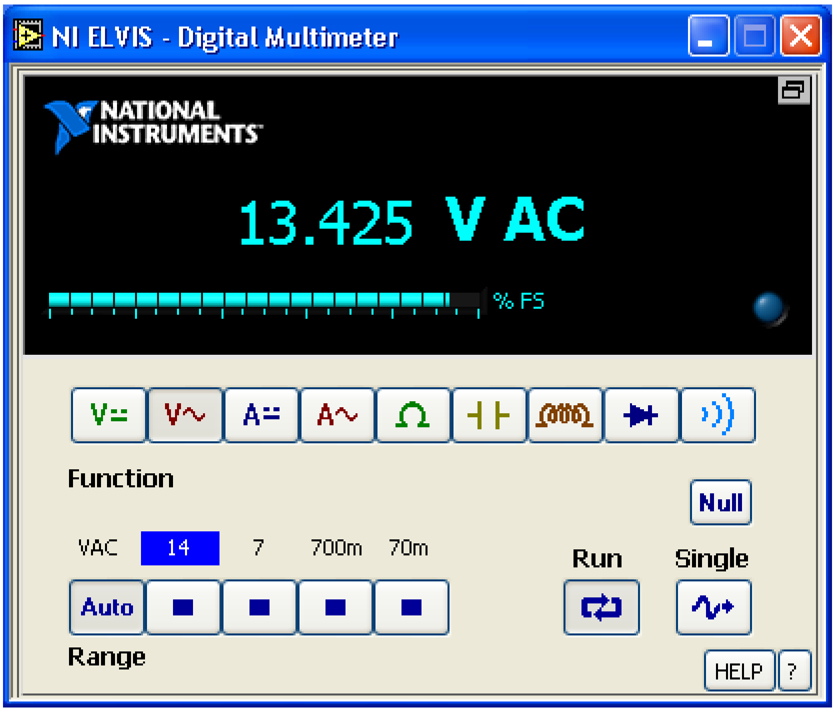

Figure 6.3 Stepped down AC input

6.2.2 Rectified Unregulated DC voltage from (IN4007) Diode Bridge Rectifier

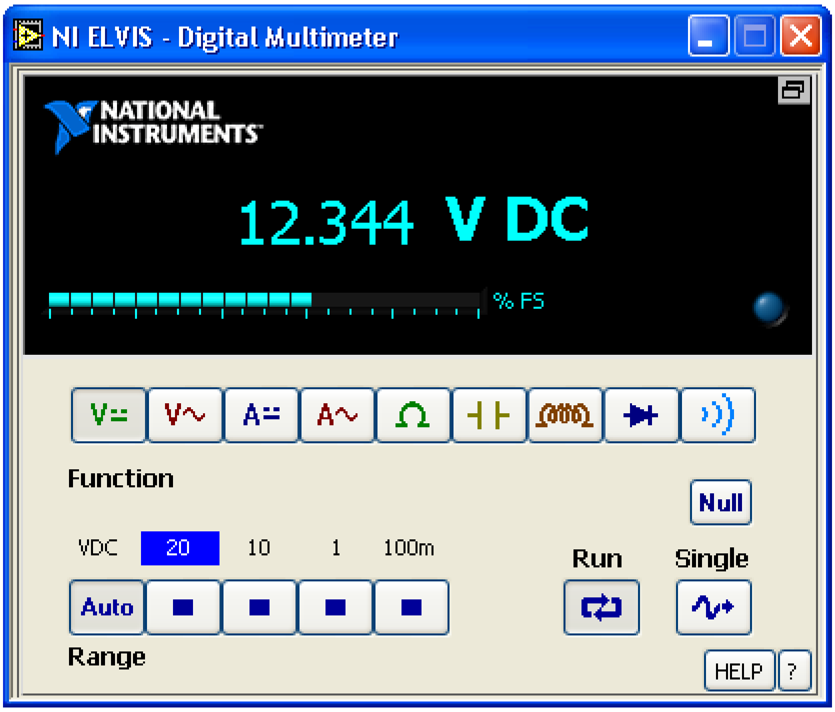

Figure 6.4 Rectified Unregulated DC

6.2.3 Output waveform from the Filter capacitor

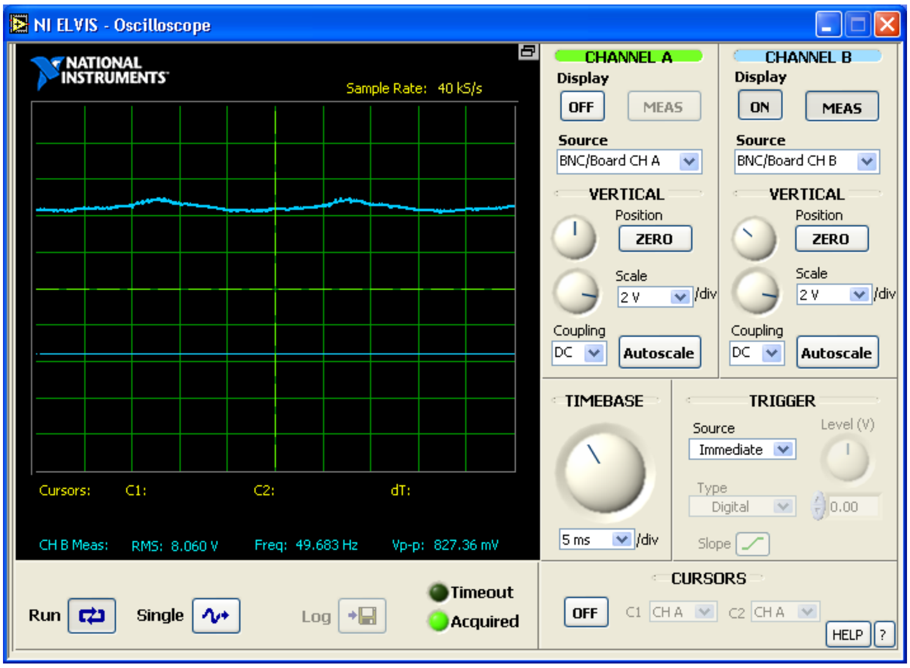

Figure 6.5 Unregulated DC From filter Capacitor

6.2.4 Chopped DC From the MOSFET switch

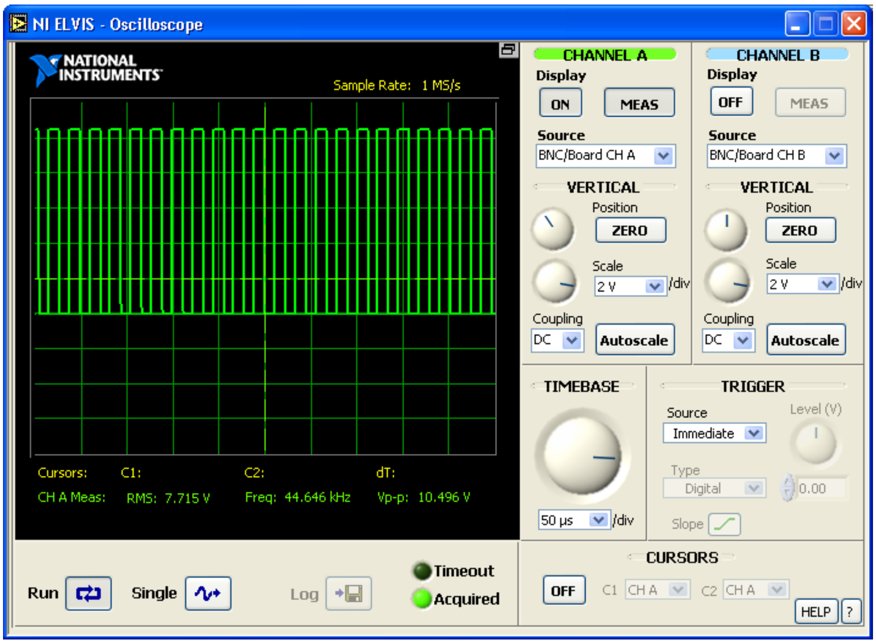

Figure 6.6 Mosfet Chopped DC

6.2.5 Output from High Frequency (40-50 KHz) Transformer taking in chopped DC .
This Transformer also Isolates input from output.

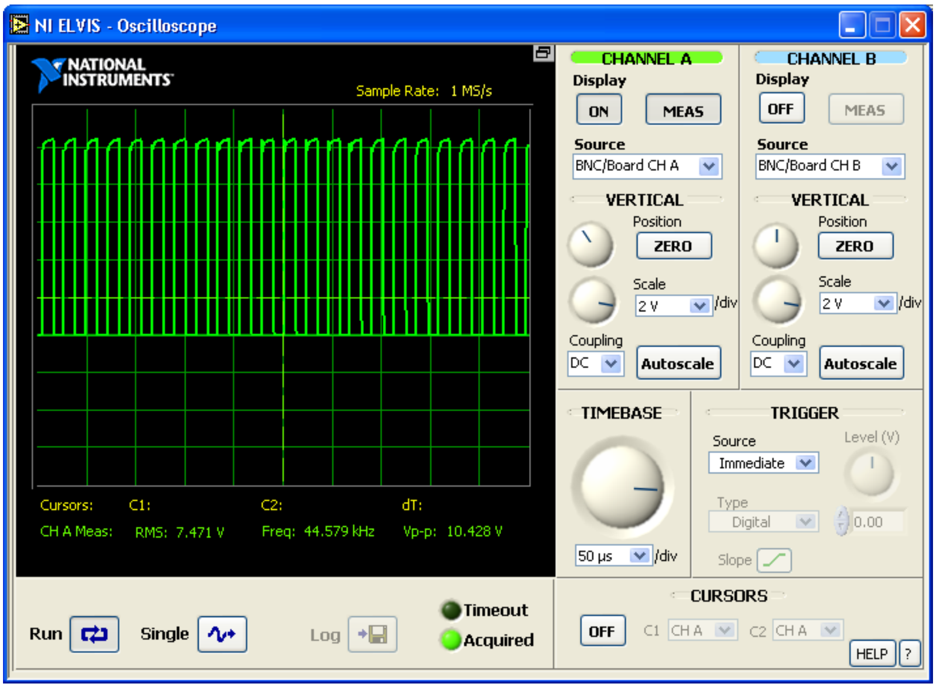

Figure 6.7 High Frequency Transformer Output

6.2.6 Output from Bridge Rectifier designed from 1N4148 High frequency Diodes.
An approximate DC signal

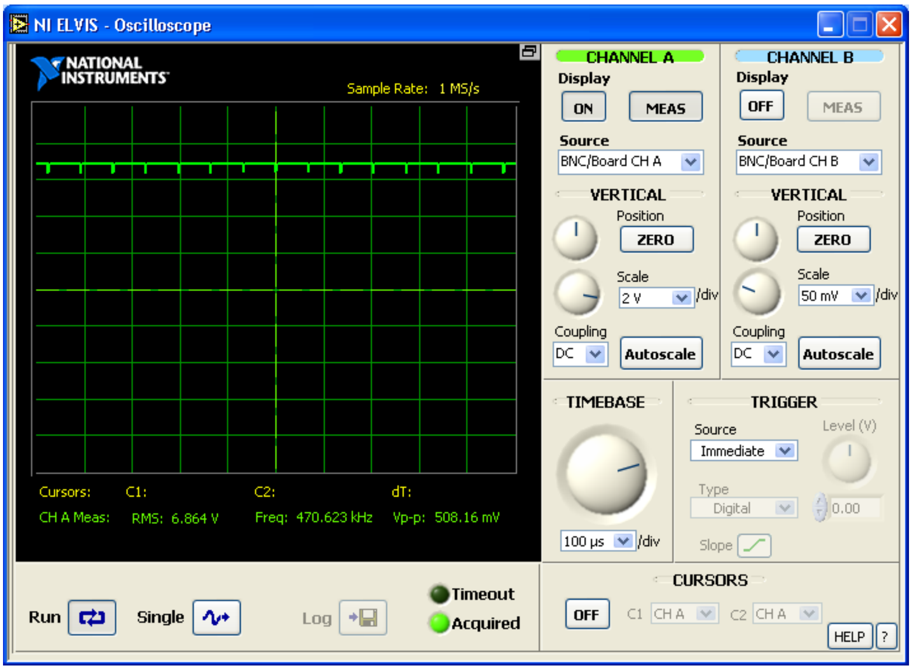

Figure 6.8 High frequency Diode Rectifier Output

6.2.7 Final Output of the SMPS

An stabilized voltage of 5 V maintained with aid of feedback mechanism and the Voltage Regulator LM7805

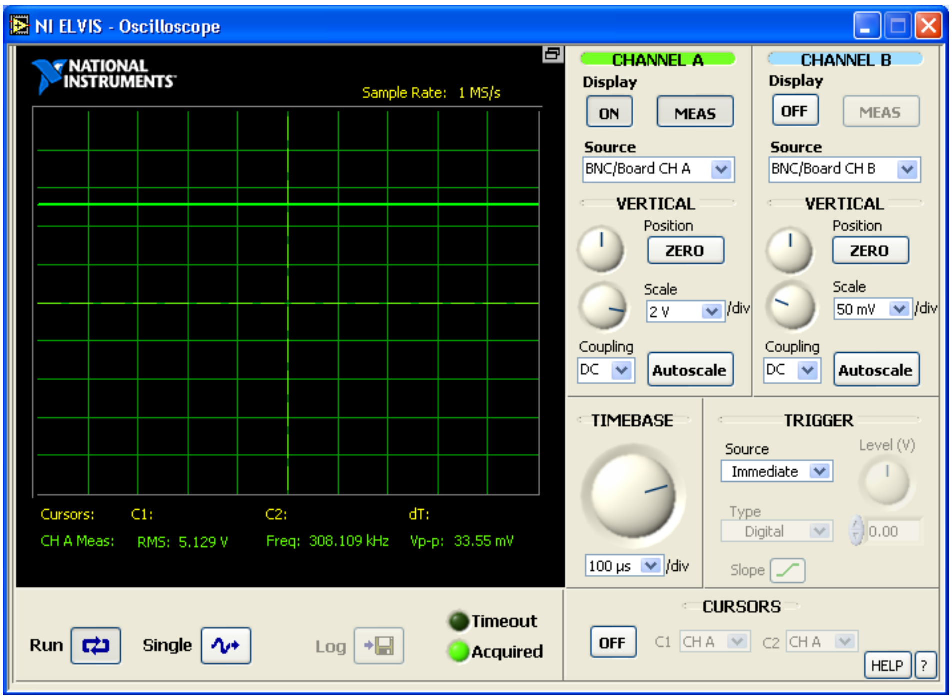

Figure 6.9 SMPS Output

Feedback Circuit

6.2.8 555 Timer based Square wave generator circuit output

44.4Khz Square wave Signal

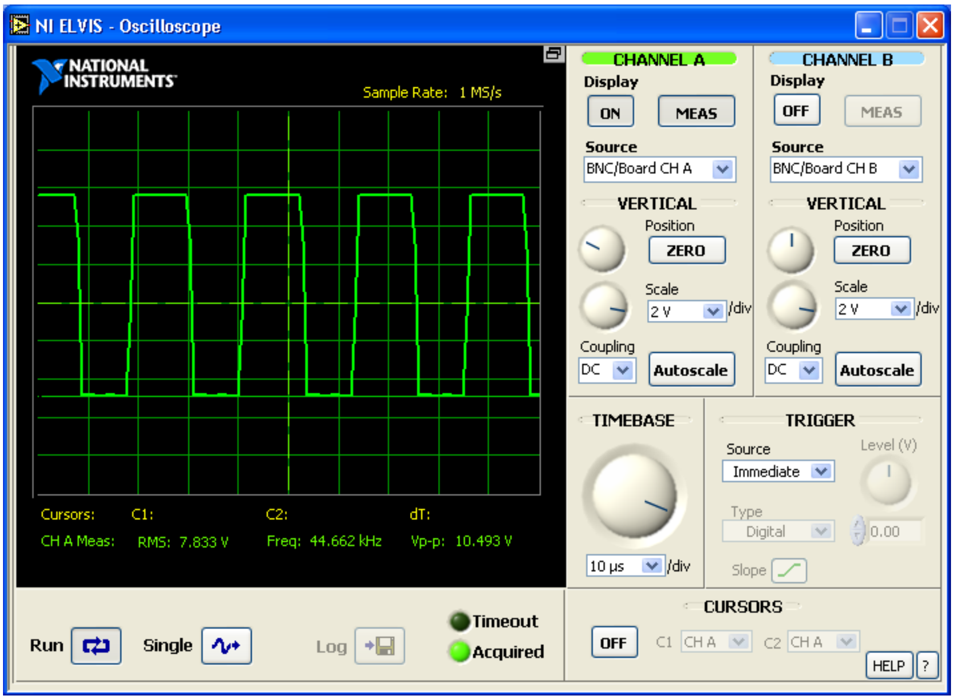

Figure 6.10 555 Timer Generated Square wave

6.2.9 Sine wave generated from TLO6021 OpAmp based circuit taking as input the square wave generated from 555 Timer based generator circuit.

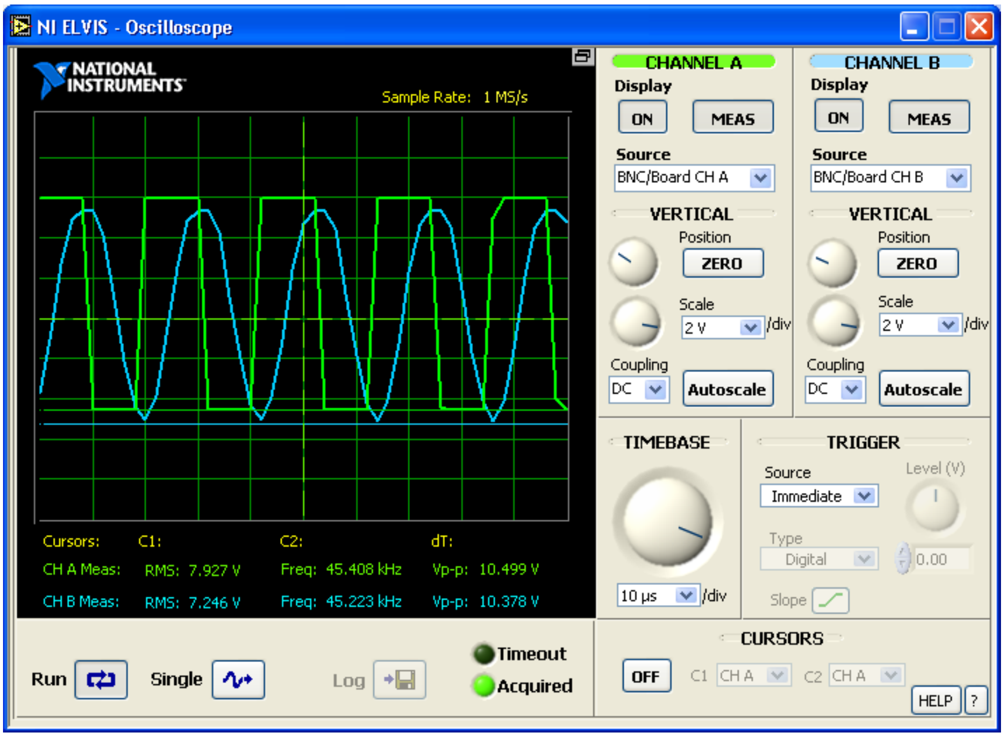

Figure 6.11 Sinewave generated from Opamp TLO6021

6.2.10 The sine wave generated above is compared with the final SMPS Output And a PWM wave is generated to drive the MOSFET switch in a way that the output is regulated back to fixed desired value (5V) if it deviates.

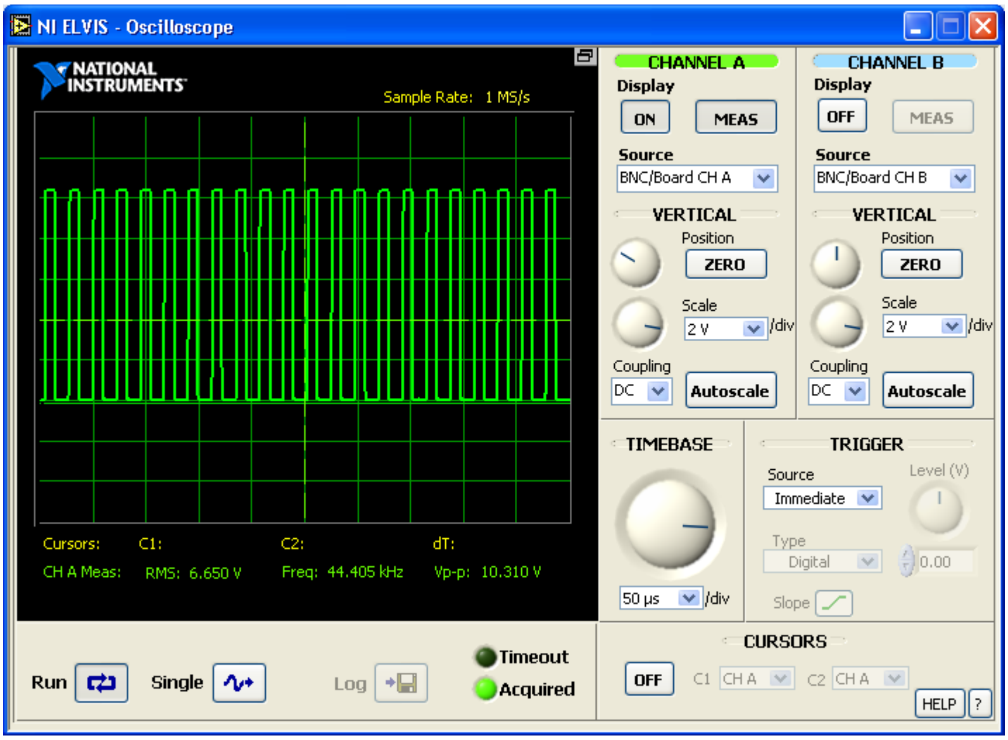

Figure 6.12 Feedback PWM Signal

CHAPTER 7

CONCLUSION

7.1 CONCLUSION

- Suitable components were selected and tested for desired performance. Functional verification was performed on combined circuit of the selected components for open loop network both in NI MULTISIM and on NI ELVIS. PWM based feedback network was successfully designed tested and implemented both in NI MULTISIM and in Hardware using NI ELVIS Suite. The Design and implementation of desired SMPS circuit was successfully completed.

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- *Somnida Ratanapanachote, Han Ju Cha, and Prasad N. Enjeti, Fellow, IEEE,* **A Digitally Controlled Switch Mode PowerSupply Based on Matrix Converter,** *IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 21, NO. 1, JANUARY 2006*
- *Z. John Shen, Senior Member, IEEE, David N. Okada, Fuyu Lin, Samuel Anderson, and Xu Cheng, Member, IEEE,* **Lateral Power MOSFET for Megahertz-Frequency,High-Density DC/DC Converters,** *IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 21, NO. 1, JANUARY 2006*